FY 2017 Center Innovation Fund Annual Report

Highlights/Abstract Section

HIGHLIGHTS/ABSTRACT (completed projects)

16-1. Cold Plasma Cleaning and Disinfection of Produce and Surfaces

PI: Paul Hintze Ph.D., paul.e.hintze@nasa.gov

Activity Type / Phase: Completed

Primary TA: TA 6.3.1.8 Human Health and Performance: Medical Equipment Sterilization

Other TA's: TA 6.1.4.10 Environmental Control and Life Support Systems and Habitation Systems: Vegetable Cleaning and Safety Verification

Start TRL: 2 / **End TRL:** 4

Goal / Gap

Goal

This project evaluated the feasibility of low pressure cold plasma (CP) for two applications: disinfection of produce grown in space and sterilization of medical equipment in space.

Gap

Currently there is no ISS capability for disinfecting pick and eat crops, food utensils, food production areas, or medical devices. This deficit is extended to projected long duration missions. Small, portable, cold plasma devices would provide an enhanced benefit to crew health and address issues concerning microbial cross contamination. The technology would contribute to the reduction of solid waste since currently crews utilize benzalkonium chloride wet wipes for cleaning surfaces and might use PRO-SAN wipes for cleaning vegetables.

CP cleaning/disinfection/sterilization can work on many surfaces, including all metals, most polymers, and this project evaluated produce. Therefore CP provides a simple system that has many different cleaning application in space: produce, medical equipment, cutlery, miscellaneous tools.

Approach / Innovation

Approach

Low pressure CP, using breathing air as the plasma gas, has recently been shown to be effective at precision cleaning aerospace hardware at Kennedy Space Center and is a relatively new technology that is showing promise for disinfecting agricultural commodities. This project will evaluate if low pressure CP can disinfect or sterilize materials. Plasma cleaning is a dry, non-thermal process, which can provide broad spectrum antimicrobial activity yet causes little to no damage to the object being sanitized, especially when utilizing living material such as seeds or pick and eat crops. Since CP uses no liquids, it has the distinct advantage when used in microgravity of not having to separate liquids from the item being cleaned. Low pressure CP has

the disadvantage of requiring a vacuum pump. However, the plasma created in low pressures is very good at reaching hidden surfaces where the plasma created at atmospheric pressure is line of sight.The project was conducted in collaboration with the Advanced Food Technology team in the Johnson Space Center Space Food System Laboratory, who are evaluating an atmospheric pressure CP system.

CP equipment was utilized and process parameters were manipulated (i.e. treatment time, gas pressure, plasma power) to evaluate the recovery/inactivation of the natural flora and/or microbial pathogens that were enumerated using standard microbiological techniques. This project focused on the disinfection of 1) salad crops inoculated with *Escherichia coli,* 2) metal coupons inoculated with 2 bacteria, *E. coli and Bacillus pumilus SAFR-32* and one fungus, *Aspergillus niger,* 3) metal materials chosen as surrogates for medical equipment and instruments, specifically threaded rods (hemostat and forceps gripping surfaces) and tubing with narrow inner diameters (needles and potable water dispenser) inoculated with *Bacillus pumilus SAFR-32* and finally an ISS potable water dispenser needle also inoculated with *B. pumilus*.

Innovation

CP treatment was able to achieve ~6 $\log_{10}$ (or > than detection limit) reduction in viable organisms on metal. These results included tests on flat coupons and complex parts such as threaded rods and small tubes. Disinfection was successful on a piece of spaceflight hardware, the Potable Water Dispenser (PWD) needle that is used on the International Space Station (ISS). The PWD needle is shown in Figure 1 below. SEM imaging showed that low pressure CP treatment reduced the size of organisms, however the total number remained the same. CP is a waste and consumable free disinfection method for space travel.

Figure 1. Left image: the PWD needle. Right image: the PWD needle being used to rehydrate a food package.

CP disinfection was less effective on produce and the produce quality was negatively impacted by exposure to the plasma.

Results / Knowledge Gained

All produce used in these studies was grown in controlled environment chambers allowing for consistency in naturally occurring microbial flora as compared to market purchased produce. Produce was inoculated with *Escherichia coli* ATTC# 11775 bacteria to study disinfection capabilities of plasma at different exposure times. Disinfection efficacy was determined by calculating the log reduction in viable bacteria compared to untreated controls as indicated by plate counts. Figure 2 shows radishes outside and inside the CP chamber. The purple glow is the plasma. CP disinfection of produce resulted in only a 2 to 3 $\log_{10}$ reduction in viable organisms and the produce was negatively impacted during plasma exposure. The negative impacts included wilting lettuce, freezing produce because of the evaporative cooling of water, and skin damage to cherry tomatoes. Therefore, low pressure CP is not a good option for disinfection produce.

Figure 2. Radishes exposed to plasma at 0.80 mbar pressure.

CP disinfection was successful on all metal parts tested. This included difficult to clean parts such as 0.027 inch inner diameter tubing. Parts with complex geometries were disinfected just as well as flat metal coupons, but required longer CP exposures of up to 1 hour. Figure 2 shows the reduction of A. niger on flat metal coupons. After 15 minutes of exposure, viable A. niger had been reduced to below the detection limit.

Publications: Paul E. Hintze; Carolina Franco; Mary P. Hummerick; Phillip Maloney; Lashelle E. Spencer, "Evaluation of Low-Pressure Cold Plasma for Disinfection for ISS Grown Produce and Metallic Instrumentation." 47th International Conference on Environmental Systems, ICES-2017-196.

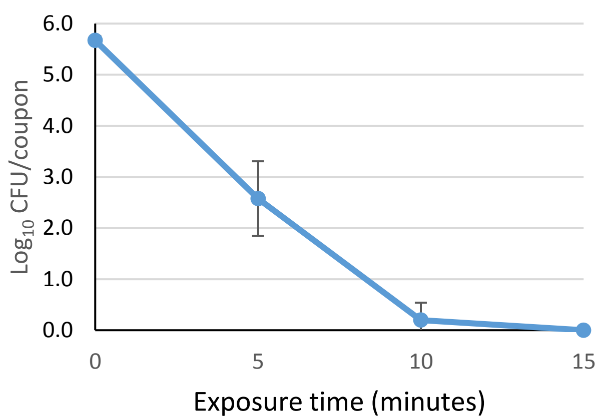


Figure 3. Reduction of viable *A. niger* spores on coupons. *Values represent the means of three replicate runs ± standard deviation.*

New Technology Reports:

- E-NTR# 1493323128: Cold Plasma Cleaning and Disinfection of Produce and Surfaces

Technology Maturation Opportunities

This technology is ready for testing with more types of parts and development of a spaceflight unit.

Partnerships

This project was conducted in collaboration with the Advanced Food Technology team in the Johnson Space Center Space Food System Laboratory, who evaluated an atmospheric pressure

CP system for produce disinfection. Microbial analysis methods were coordinated between our two labs.

16-2. Magnetic De-Spinning of Space Objects

PI: Robert Youngquist Ph.D., robert.c.youngquist@nasa.gov

Primary TA: TA 2.2.1, In-Space Propulsion Technologies; Electric Propulsion

Start TRL: 1 **End TRL:** 2

Goal: To determine whether magnetic fields can be used to de-spin objects in space, including defunct satellites, space debris, and possibly asteroids.

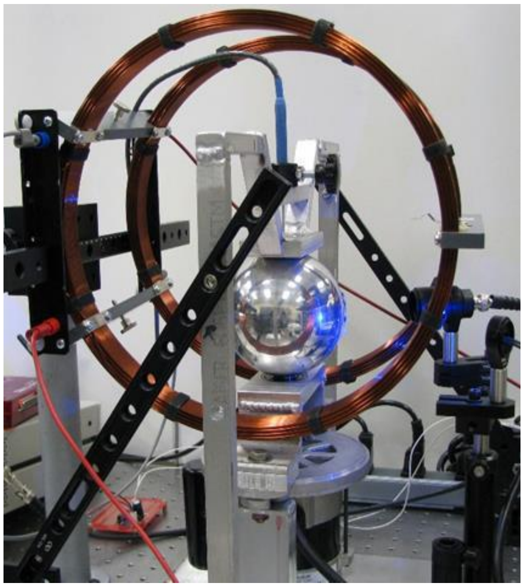
Gap: Objects in orbit about the Earth rotate such that a service spacecraft cannot grapple with them, and few techniques are available to de-spin a space object without causing damage to it or to the service spacecraft. Electrostatic approaches have been considered, and magnetic approaches have promise but have not been sufficiently studied. However, recent papers in this area, including our paper, published as the cover article in the March 2016 issue of the American Journal of Physics, show that further development of this capability is beginning. However, two areas are still poorly developed: the interaction of a magnetic field with a larger object or even a solid conducting object such as an asteroid, and the orbital dynamics that occur between the object that is being de-spun, the spacecraft supplying the magnetic field, and either the Earth or the Sun.

Approach and Innovation

Approach: The project was split to address these two areas. KSC researchers developed modern theory on the interaction of a uniform magnetic field with a rotating thick/solid sphere and experimentally tested their predictions to fill this knowledge gap. Cornell University researchers, with Air Force support, explored the orbital dynamics of a magnetic-field-generating satellite with a rotating satellite, coupling the orbital pseudo-forces against the real forces caused by the electromagnetic interaction. The goal of both of these efforts, which are technically unique yet crucially related, was to create a capability to de-spin space objects—a capability that would enable future exploration efforts.

Innovation: The fundamental theory of the interaction of the rotating conductive sphere with both uniform and non-uniform magnetic fields was first developed by Hertz in the 1880s. He predicted the eddy currents generated in the sphere and figured out a way to handle the feedback process, but his work is in archaic notation (prior to the development of vector calculus), making it very cumbersome to follow. The KSC researchers not only modernized Hertz' work, but also extended it and verified it experimentally. The understanding gained here supported the application to de-spinning satellites and to a variety of induced-eddy-current problems. The highly favorable reaction to our first paper shows that no one else is doing this work and that the physics community sees a need for it. The Cornell/Air Force effort on orbital dynamics came up with several interesting concepts on the interaction of two or more objects in orbit that are coupled with a controlled force. Concepts related to transfer of angular momentum and long-term de-spinning were addressed.

Results and Knowledge Gained: The KSC effort derived a theory to predict the interaction of an applied magnetic field with a rapidly rotating sphere and have constructed an experiment to verify that theory. Figure 1 shows an aluminum sphere mounted to a motor that rapidly rotates in the presence of a magnetic field generated by the Helmholtz coils shown. A hole drilled into the top of the sphere allows a magnetic field probe to measure the field inside the sphere, and an LED light source is used to monitor the rotation speed of the shell.



Figures 2 and 3 show the magnetic field components in the center of the sphere, aligned with the applied field and perpendicular to the applied field. The center was selected for measuring the field because it has the least movement and is simplest to probe with our sensor. The dots are measured data, showing reasonably close matching with the values predicted by theory, represented by continuous lines. This is the first experimental verification of this theory, which complements our earlier work on a rapidly spinning shell.

Figure 1. Aluminum sphere in a uniform magnetic field.

The maximum de-spinning torque occurs when the parallel field component of the B-Field is cancelled within the sphere. This occurs at around 24 Hz in Figure 2. However, the maximum de-spinning torque is not just dependent on the rotation frequency, f, but also the sphere radius, r_2, the conductivity of the sphere, σ, and the vacuum permeability, μ_0. This dependence is defined mathematically as $r_2\alpha$, where $\alpha = \sqrt{\mu_0 \sigma 2\pi f}$. Figure 4 shows this torque dependence is a maximum for $r_2\alpha=3.34$, the sweet spot for de-spinning a space object. How fast the object slows down is dependent on the starting point on this curve. The shortest slow down times will occur for $r_2\alpha$ less than or equal to 3.34.

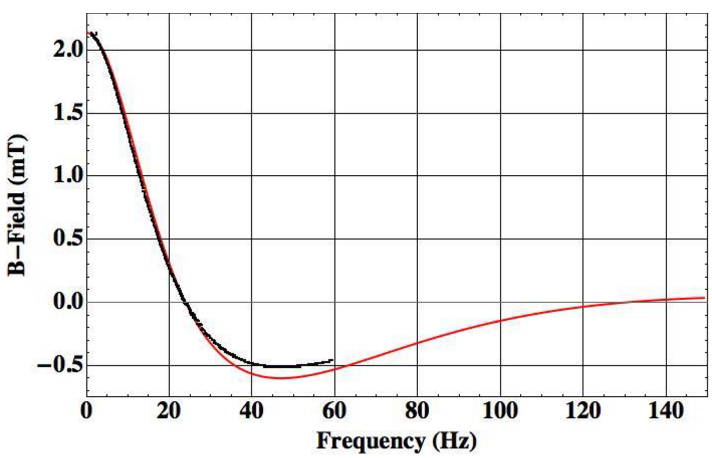


Figure 2. The theoretical prediction (solid red line) and the experimental measurements (black dots) of the magnetic field inside of the solid spinning sphere when exposed to a uniform magnetic field perpendicular to the sphere's rotation axis. This plot shows the magnitude of the field component parallel to the applied field versus the sphere's rotational frequency.

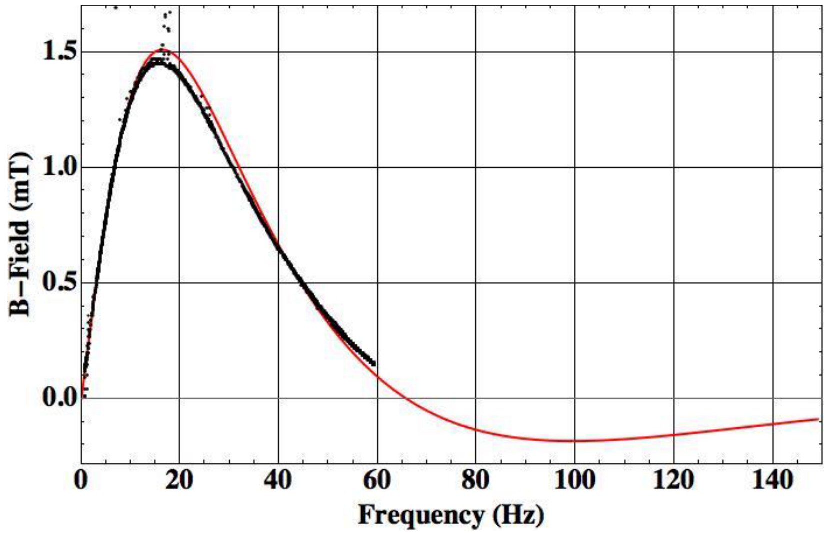


Figure 3. The theoretical prediction (solid red line) and the experimental measurements (black dots) of the magnetic field inside of the solid spinning sphere when exposed to a uniform magnetic field perpendicular to the sphere's rotation axis. This plot shows the magnitude of the field component perpendicular to the applied field versus the sphere's rotational frequency.

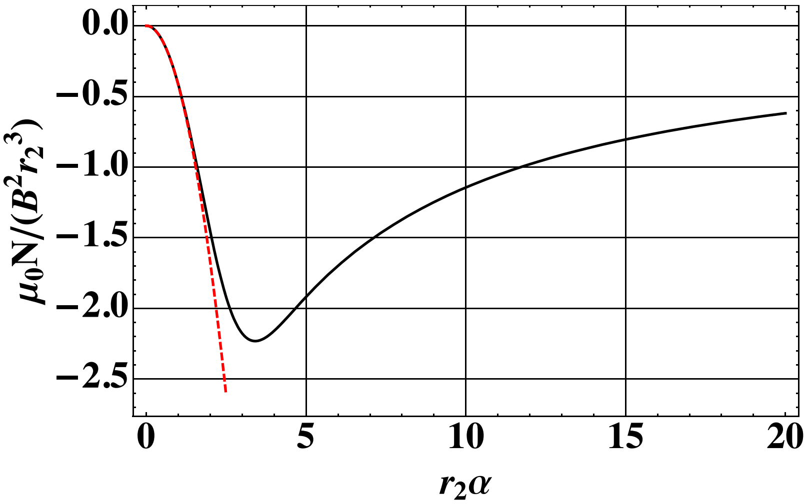


Figure 4. The solid black curve shows the total deceleration torque in the direction of rotation (x-axis) for a solid sphere in a uniform magnetic field along the z-axis. The dashed curve is the solution resulting from the simplified solution for the slow-speed rotation case. The plot units are dimensionless.

This work has been published in the August 2017 issue of the American Journal of Physics and will be the subject of an invited talk at the American Association of Physics Teachers Winter Meeting in January 2018.

The Cornell/Air Force effort has modelled the orbital dynamics of a pair of chaser satellites approaching and locking onto a defunct spinning space satellite. Issues such as orbital stability, orbital angular momentum, relative motion, de-spinning time, mass and energy issues, and orbital orientation have been considered and incorporated into the model. The result has been the determination that under the correct conditions that it is feasible to use a magnetic field generated by a pair of opposing satellites to de-spin a defunct rotating space object.

Technology Maturation Opportunities: Dr. Nurge and Dr. Youngquist have prepared and submitted another manuscript describing the interaction of a non-uniform magnetic field with a rotating sphere and hope to have it published in late 2017 or early 2018. Additionally, they received notification that their FY18 CIF proposal, ECAPS – Eddy Current Approach and Proximity Satellite, was accepted for award. This new project will build on this prior work, but now uses a time varying magnetic field to see if the team can devise a servicing spacecraft for the ISS. Professor Peck and Dr. Leve will continue to partner with KSC in this area.

Partnerships: Dr. Mason Peck of Cornell and Dr. Frederick Leve of the Air Force Office of Scientific Research are partners in this work and have brought substantial orbital dynamics expertise to the project.

16-3. Using the Solar Spectrum to Convert the Mars Atmosphere into Fuel with Novel Photocatalysts

PIs: Paul Hintze, Ph.D., paul.e.hintze@nasa.gov / Anne Meier, anne.meier@nasa.gov

Co-Is: Prital Thakrar, prital.j.thakrar@nasa.gov, Jan Surma, jan.m.surma@nasa.gov, Jerry Buhrow, jerry.w.buhrow@nasa.gov, Michael Kosiba, michael.l.kosiba@nasa.gov, Tracy Gibson, Ph.D., tracy.l.gibson@nasa.gov

Primary TAs: TA 07 Human Exploration Destination Systems

Start TRL: 2 **End TRL:** 3

Goal: To demonstrate the conversion of CO_2 and water to fuel in the presence of visible light spectrums of Earth and Mars using novel catalysts in a photoreactor.

Gap: CO_2 conversion to fuels using available solar spectrum on Earth and Mars, specifically the visible light range.

Approach: This FY16 CIF work was funded from March 1, 2016 to April 30, 2017. This project aimed to investigate and demonstrate the conversion of CO_2 in the presence of H_2O vapor to fuel (i.e., CH_4), using novel photocatalysts in a photocatalytic reactor under Mars and Earth simulated solar spectrums. The photocatalyst materials were initially synthesized from "An In-Depth Study of Photocatalytic Charge Transport and Material Development through Synthesis, Characterization, and Photocatalytic Properties for *In Situ* Resource Utilization (ISRU) and Fuel Production on Mars," a Science Innovation Fund (SIF) project. Further developments at Kennedy Space Center (KSC) continued during this CIF project, where bulk batches of the photocatalyst materials were synthesized at KSC and the University of South Florida (USF) for photoreactor testing at KSC with support and collaboration from the Engineering Services Contract (ESC). The photocatalyst materials underwent structural/morphology analysis and optical characterization and were believed to have band gap values in the regime for photocatalytic H_2O splitting and CO_2 reduction. The concept of using solar irradiation for CO_2 reduction and H_2O splitting for fuel production is illustrated in Figure 1. The hydrogen evolution reaction (HER) produces available hydrogen that may react with CO_2 in a series of reduction and oxidation reactions for the production of fuels such as CH_4, which is a necessity for liquid O_2 and liquid CH_4 propulsion systems of deep space, as well as fuels used on Earth.

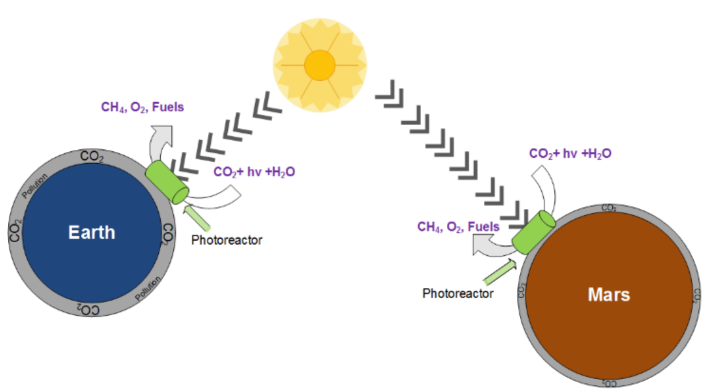


Figure 1. Concept of the CIF project to use visible light from solar irradiation for CO_2 conversion.

Innovation: A photocatalytic reactor was designed, built and constructed to demonstrate the feasibility of conversion of CO_2 to fuel for ISRU Mars energy production. The photocatalytic reactor provided a platform for photocatalytic performance testing of novel photocatalysts in the presence of CO_2 at ambient pressure, and multiple catalyst support types using a solar simulator or LED light irradiation.

Results and Knowledge Gained: A photocatalytic reactor was constructed to demonstrate the feasibility of conversion of CO_2 and H_2O to fuel with novel photocatalysts. The materials utilized were MoS_2, $(ZnO)_{1-x}(GaN)_x$, and $(ZnO)_{1-x}(AlN)_x$ with Earth and Mars surface irradiation conditions. Visible-light irradiation needs to be used as much as possible for photocatalysis, since it is the highest intensity of available light in the solar spectrum.

With the current data and observations, some hydrocarbon fuels were formed from the light irradiation in the presence of CO_2 and H_2O, as observed by GC FID and FTIR. The MoS_2 materials were more reactive under Earth irradiation conditions rather than Mars, due to the higher intensity of visible light on Earth. The highest CH_4 detected by the GC was at 300 minutes of exposure under Earth conditions, with 11.88 μL of CH_4. The $(ZnO)_{1-x}(GaN)_x$ materials performed comparatively well in both Earth and Mars conditions. These materials have a longer range of absorbance in VIS and IR. The best performance of $(ZnO)_{1-x}(GaN)_x$ occurred under Mars conditions with 3.5 μL of CH_4.

Repeatability of the experiments is necessary until more conclusions can be made on the CH_4 production a repeatability. The GC data did have some unknown peak formations that did not fall under the calibrated compounds investigated under the scope of this work. More investigation into these peaks with trace gas analysis can help determine what other hydrocarbons may be forming. Detection at low CH_4 concentration (<1 ppm) is also very challenging.

The initial data obtained in this CIF is still encouraging since the photocatalysts are producing some type of hydrocarbon products during light irradiation in the presence of CO_2 and H_2O. In this work, both HER and CO_2 reductions were attempted simultaneously under visible light, which is extremely challenging. One future recommendation is to break the reactions into smaller experiments, such as H_2O only, to observe hydrogen or oxygen evolution, followed by implementation of CO^2 at elevated temperatures to try and increase reaction kinetics.

Technology Maturation Opportunities: The collaboration with a university or other industry that has access to trace hydrocarbon analysis instruments such as residual gas analyzers, or methanators followed by a mass spectrometer would be useful for this trace gas detection in small sample sizes.

Follow-On Work: There are plans to submit a journal article for publication on this work after further experimentation, additional control experiments, and repeatable validation. No other formal follow on work is planned at this time. Publication may reach the academic and industrial catalysis community in hopes to instill interest in advancing materials and methods for this application.

New Technology Reports:

- e-NTR #: 1481844093, Photoreactor for CO_2 conversion
- e-NTR #: 1481660828, Transition Metal Dichalcogenide Nucleation and Growth on Quartz Fibers via Chemical Vapor Deposition

- e-NTR #: 1493673382, Synthesis, characterization and photoreactor testing with $(ZnO)_{1-x}(AlN)_x$ powders

Partnership: A Space Act Agreement (SAA) was set up between NASA KSC and USF at the start of this project. The SAA was in place ~13 months after the project start date. USF is currently carrying out density functional theory measurements using VASP software, which will possibly supplement journal article submissions, depending on the results.

Two USF students presented work at the undergraduate research poster presentation with work titled “Investigation of ZnO/GaN and ZnO/AlN solid solutions for photocatalytic conversion of carbon dioxide under visible light” (by Johnnie Cairns) and “A Comparison of ZnO/AlN and ZnO/GaN Solid Solution Photo-Catalysts for Application in the Hydrogen Evolution Reaction” (by Daniela Allbright). Dr. Venkat Bhethanabotla and Dr. John Kuhn also submitted a report titled “Synthesis and Characterization of ZnO/GaN and ZnO/AlN Solid Solutions for Photocatalytic Reduction of Carbon Dioxide to Carbon Monoxide.” These presentations are found as attachments in Section **Error! Reference source not found.**.

Anne Meier attended an invited travel workshop on “Addressing the Mars ISRU Challenge: Production of Oxygen and Fuel from CO_2 Using Sunlight” sponsored by Keck Institute for Space Studies in June at Caltech University. As a result of this workshop, Meier supported the Jet Propulsion Laboratory in a NASA Innovative Advanced Concepts (NIAC) proposal for the 2016 NIAC call titled “Fueling Mars: Solar Beam Powered Chemical Conversion.” The proposal was not selected for funding, but feedback was gathered for potential future collaborations.

16-4. Regenerative Ammonia Recovery from ISS Wastewater to Facilitate Plant Growth

PI: Gioia Massa Ph.D., Gioia.Massa@nasa.gov

Co-Is: Griffin Lunn, Griffin.M.Lunn@nasa.gov, Oscar Monje, Oscar.A.Monje@nasa.gov

Primary TA: TA 6.1.2.2, Human Health, Life Support, and Habitation System; Wastewater Processing

Other TA: TA 7.2.4, Food Production is a secondary TA

Start TRL: 1 **End TRL:** 3

Goal: To enable human survival on Mars by growing plants using nitrogen recovered from wastewater.

Gap: Removing and recycling nitrogen from wastewater is a critical technology for the International Space Station and future long-duration exploration missions. Nitrogen, as a component of ammonia and urea found in urine is valuable for plant growth, but removing ammonia from the water stream without also removing sodium (a toxin for plants) is a difficult task.

Approach and Innovation

Approach: KSC has developed a process to remove ammonia from wastewater that produces struvite, a compound of magnesium ammonium phosphate (MAP). MAP releases ammonia when heated and itself can be used as a plant fertilizer. This process could produce ammonia nitrogen for plants while also preventing the accumulation of sodium, however, concepts for capturing the released ammonia into a suitable plant fertilizer must be developed. The processes for loading ammonia from wastewater onto magnesium phosphate ($MgHPO_4$; MP) to form MAP, and for various methods of releasing ammonia from MAP to regenerate MP were studied in detail. A number of factors—such as residence time, MP particle size, pH, and regeneration temperature—were studied to optimize system performance. Following optimization, the cycling of MP ↔MAP was demonstrated to determine the factors that can control this process so that it can then be scaled for flight, as well as for other potential industrial and environmental applications, including wastewater treatment.

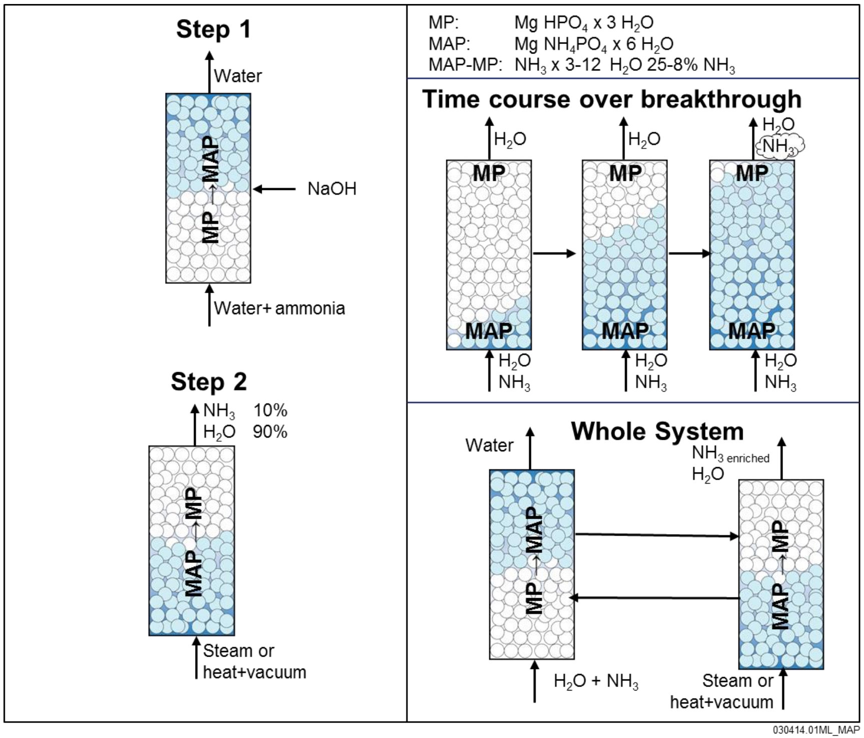


Figure 1: Basic overview of process

Innovation: The KSC regenerative ammonia removal process requires the use of MP, which is a commodity chemical, and that urea-nitrogen in urine be completely hydrolyzed to ammonia before MAP can be formed from MP. The process pumps wastewater through columns of MP, with ammonia measurements and pH adjustment being performed between column runs. Columns are thermally regenerated when saturated with ammonia to recycle the MP, and to allow this process to repeat. The conversion of MP to MAP is pH dependent, and the regeneration process can occur at low temperatures (60-100°C). A regeneration of 100% happens above 400 °C and is not normally desired. This yields a concentrated wet ammonia stream that can be used for plant growth, refrigerant, or hydrogen/nitrogen production applications.

New Technology Reports
• KSC-14124: Regenerable Ammonia precipitation method optimized for throughput KSC-14124
• KSC-14138: A process to remove and concentrate ammonia of various concentrations from waste water for further use of both products
• KSC-14147: Modified random packing to perform reactive absorption while optimizing flow characteristics

Results and Knowledge Gained: In this study, several aspects of the struvite-based regenerative ammonia recovery process were examined. First, the effects of process pH, flow and particle size on the kinetics of NH_4^+ removal from solution to produce MAP were optimized using a plug-flow reactor filled with MP. Second, the kinetics of ammonia release during low temperature (50-100°C) thermal regeneration of MAP were characterized. Third, the cyclic loading of MP with ammonia and its subsequent thermal regeneration was demonstrated over 3 cycles. Finally, a plant study testing the efficacy of MAP as a fertilizer was conducted using wheat plants.

The ammonia loading process is very sensitive to pH. The solution pH affected the solubility of MP and MAP as well as the uptake of ammonia and some other compounds. Deviations from ideal pH ranges causes the bed to become soluble in water or to amalgamate into a non-porous mineral. However gross ammonia removal rates (Kg ammonia removed/m^3 bed size-hr) were found to be orders of magnitude higher than biological ammonia removal and even ion exchange processes without the lack of selectivity found in the latter.

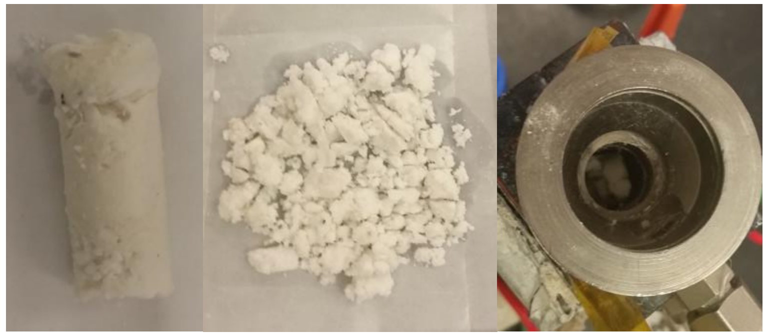


Figure 2: Loading Regeneration Bed with wet MAP

The regeneration of the MP/MAP was demonstrated in a recycling experiment. Ammonia was loaded onto MP->MAP in a plug-flow column, the wet plug was removed, cut up with a razor blade and placed in a bed for thermal regeneration. Partial removal (20-80%) of ammonia was found to occur under a low temperatures with some cycle times taking as little as 30 minutes. Total regeneration is likely not to be economically viable but not required in such a cycling system.

A plant growth study was conducted to demonstrate if MAP or MP are suitable fertilizers when compared to a commercial slow release fertilizer (Nutricote 14-4-14). MP could be obtained from urine salts and MAP would be produced from MP loaded with ammonia from urine. Wheat cv *Apogee* was grown in four fertilizer treatments: control (7.5 g/L Nutricote), Low NPK (2 g/L Nutricote), MAP (2 g/L Nutricote + MAP + K_2SO_4), and MP (2 g/L Nutricote + MP + K_2SO_4 + $(NH_4)_2SO_4$). The Low NPK treatment was amended with either MAP or MP plus enough $(NH_4)_2SO_4$ and K_2SO_4 provide similar N and K percentages as the control. Wheat plants grown in 7.5 g/L 14-4-14 Nutricote were taller, had wider leaves, taller stems, more tillers and darker leaves than the plants grown at Low NPK (2.0 g/L Nutricote). Adding MAP and the same potassium content restored the height and leaf width compared to the Low NPK plants, but dramatically increased tillering compared to the control plants. The MP plants had similar height and chlorophyll content as the MAP plants, however, they were not as healthy, appeared to be delayed in development, and they had a salty deposit at the bottom of the stems.

Three loading / regeneration cycles were conducted sequentially. Each cycle consisted of loading MP with ammonia in the plug-flow reactor, transferring the MP/MAP to a heated bed, thermally desorbing ammonia and drying the MP/MAP, and transferring it to the plug-flow reactor to be loaded again. This approach resulted in loss of mass during transfer to and from the plug-flow reactor to the bed. A major finding was that the regeneration /drying process changes the particle size of the solid. During loading, poor control of pH can lead to the amalgamation of the particles, which causes increased pressure drop. The thermal regeneration is able to reset the particle size by completely breaking down the amalgamation of the particles. Another observation was that the kinetics of the ammonia removal were faster after regeneration so that the ammonia removal was best conducted in single passes instead of in a continuous flow. Further tests will be needed to develop an loading/regeneration procedure to allow suitable ammonia recovery rates with long-term bed life. Testing is needed to optimize the regeneration and reusability process for the expended column materials.

Technology Maturation Opportunities: KSC Technology Transfer and Legal have been seeking appropriate intellectual property protection and are soliciting potential customers and collaborators to develop this technology for terrestrial applications. No internal collaboration has been done to further this technology, and working with other Centers could be useful, especially with integration of the new technology into the designs of larger environmental control and life support systems (ECLSS). This process is patent-pending.

Partnerships

• A subcontract has been established with Dr. W.H. Lee, P.E., of the Civil, Environmental, and Construction Engineering Department at the University of Central Florida. Dr. Lee and his laboratory studied the solubility equilibrium of the struvite reaction. In addition, Dr. Lee's laboratory examined solubility optimization in order to minimize solid losses during operation Dr. Lee's work will provide NASA-KSC with the proper conditions to run a "guard" column to minimize leakage of magnesium, phosphate, or ammonia.

• A second partnership has been established with Dr. B. Tansel, P.E., Civil and Environmental Engineering Dept. at Florida International University. Dr. Tansel was funded by Florida Space Institute to study ammonia removal and is focused on adapting this technology to wastewater.